HOLD THAT WATER!

For those who really want light on the subject, here is a lucid explanation of the crucial role of water in the performance and over-all economics of concrete construction.

By Edward E. Bauer and George W. Hollon*

"WHAT ARE THE FACTS regarding extra water that is often added to concrete to make it easier to handle? I just can't understand these engineers," says the man who must handle the freshly-made concrete. They want the concrete kept wet during curing, but when I'm trying to get it out of a truck, they say to leave the water out. I really don't believe they mean to be unreasonable, but why do they make it so hard on my back?" This is a typical dilemma for a number of people who are handling concrete without knowing the facts.

Quality concrete is the kind of concrete we are all interested in. What is quality concrete? Quality concrete is concrete that has been properly designed, produced, placed, compacted, finished and cured. The designing of the mix involves the selection of suitable materials and the determination of the proper amounts of each to perform a given function. Production must be well controlled so that the concrete is uniform within the batch as well as from batch to batch. Uniformity within the batch must be secured while the concrete is in the mixer; once the concrete is out of the mixer most placing, compacting and finishing operations tend to produce varying degrees of non-uniformity—a sort of unmixing of the concrete, as it were. Inclusion of additional amounts of water almost inevitably means that the concrete for that particular job can't be properly classed as quality concrete.

There are many items in the various stages of the whole process that may be varied, or may be out of line with "good practice," so that the concrete may not be designated as quality concrete. Each batch of coarse aggregate, fine aggregate, cement and water must be accurately weighed and must be adequately mixed so that a uniform mixture is obtained. In the placing of the concrete, care must be exercised not to permit the concrete to segregate, thus permitting the larger pieces of aggregate to be deposited in one place and all the mortar in another location. A certain amount of compaction is necessary in most instances but when the amount of compactive effort becomes excessive there is segregation and the concrete loses some of its quality. Finishing operations at the proper time and adequate curing are also essential in the making of quality concrete.

Concrete is an engineering material; when handled properly it will produce a durable, lasting structure. When handled improperly, it will often scale, disintegrate or deteriorate readily. In a few hours after casting, concrete will set and take the shape of the form in which it is placed. This change from the plastic to the solid state is what confuses most people regarding the amount of water to be used in making the concrete.

If water is added while the concrete is still plastic, or if too much water is used in mixing the concrete, the space which was occupied by this extra water will be void space since the addi-

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tional water will have evaporated. If the water were not present in the beginning the concrete would not occupy as much space and the volume of voids would be smaller.

This can best be illustrated by looking at Figure 1 where two cement cylinders are shown in balance on a scale. The cylinder on the left was made with 9 gallons of water per sack of cement and the picture shows that it occupies a large amount of volume. The cylinder on the right was made with only 4 gallons of water per sack and it occupies a much smaller volume. In both cases the amount of cement used in making the cylinders was identical. The excess water has evaporated and this is the reason the two cylinders are of equal weight. Concrete made with 9 gallons of water per sack of cement would also be porous, similar to the cylinder on the left. Concrete made with 4 gallons of water per sack on the other hand would be very dense and durable.

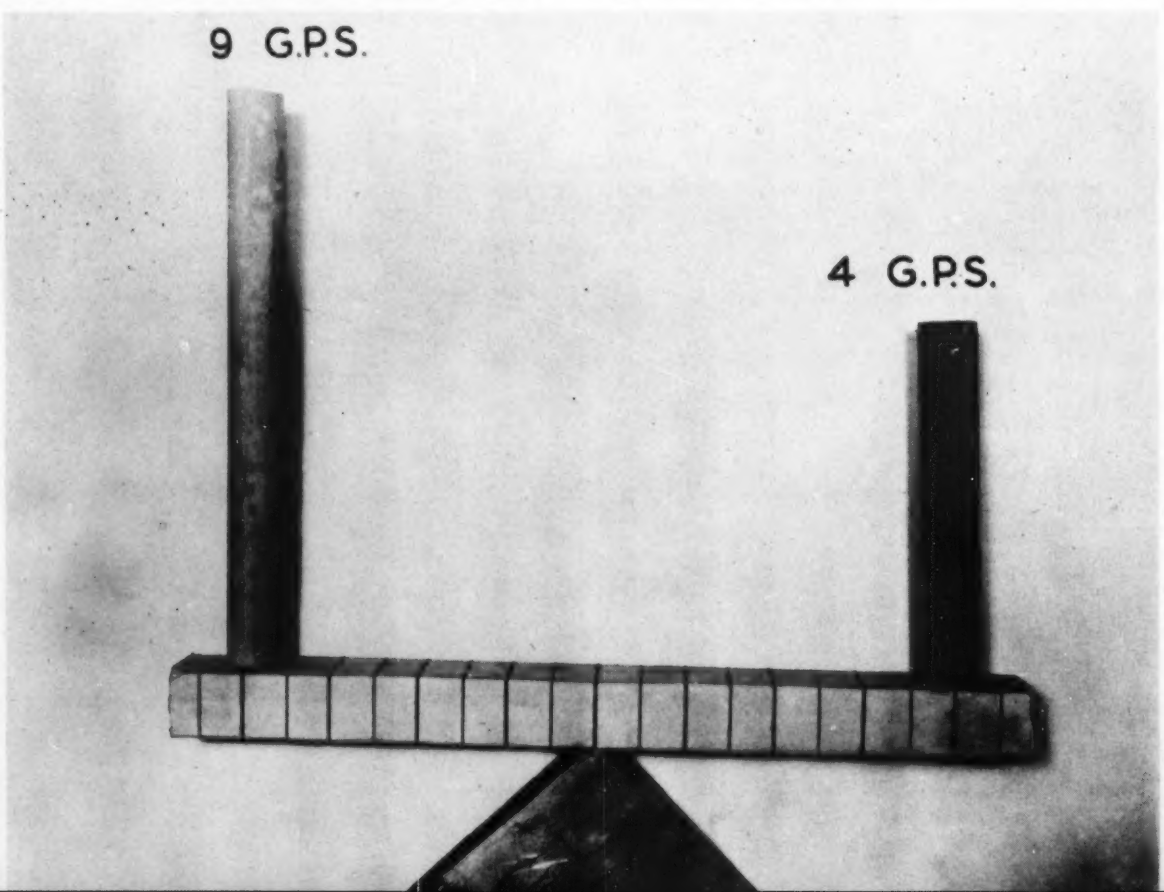
Cement cylinders made with 4, 5, 6, 7, 8, and 9 gallons of water per sack of cement are shown in Figure 2. No aggregates were used in making any of the cylinders designated cement cylinders. Again it can be seen that the volumes of the cylinders increase as the number of gallons of water increases. Since all of the cylinders have the same weight, the tallest cylinder contains the largest volume of air voids, whereas the shortest cylinder has the smallest volume of voids.

Concrete may be considered as a combination of aggregates and a cement paste. The cement paste is composed of cement and water and is the material that binds the particles of aggregate together. The binding action stems from the cement when it is mixed with water. The amount of water actually combining with the cement in the hydration process is of the order of 3.0 gallons per sack. Much more mixing water than this is needed to produce concrete that can be properly placed and finished, but all the water used over and above that needed for hydration of the cement tends to dilute the paste, producing a product of lower quality.

Strength is indicative of quality. When the paste portion of the concrete is made with a low quantity of water, say 4 to 5 gallons of water per bag of cement, concrete strengths may be of the order of 6,000 pounds per square inch. On the other extreme, if 9 gallons of water are used per bag of cement, the strength may be as low as 2,000 pounds per square inch, or even lower. The amount of water used in concrete per bag of cement is a major factor in the strength of the resulting concrete.

Durability is another very important quality for

Figure 1: Two hardened neat cement cylinders made with different amounts of water for the same amount of cement are shown in balance on the cross arm, indicating that they are of equal weight.



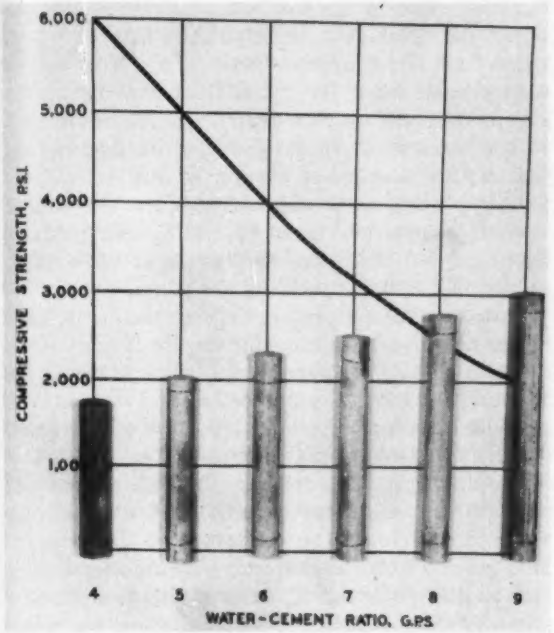


Figure 2: Hardened neat cement cylinders of equal weight made with varying amounts of water per sack of cement. Heavy black line indicates decreasing strength with increasing water-cement ratios.

concrete to possess. Here again the amount of mixing water per bag of cement has a direct bearing on the durability of concrete. Durable concrete has the ability to resist the action of freezing and thawing and wetting and drying to which it is subjected in northern climates. If the concrete contains large enough void spaces, water may fill these spaces. If the spaces are full when freezing takes place, the expansion of the water when it freezes will cause the concrete to fail. Water expands from 7 to 9 percent when it freezes and exerts a force greater than the tensile strength of concrete. Individual void spaces in the paste decrease in size as the amount of mixing water per bag of cement decreases. At about 6 gallons per bag the size of the void spaces becomes sufficiently small to resist the ready intrusion of water, with the result that the concrete may rarely become saturated. In the unsaturated condition there is void space into which the freezing water may expand, thus reducing or eliminating the possibility of disintegration due to this cause.

Tests on mortar specimens to determine a given weight loss of 2 percent have shown that 6 gallons of water per bag will withstand 200 cycles of freezing and thawing, whereas mortar specimens made with 8 gallons of water per bag will withstand only 80 cycles of freezing and thawing before the weight loss of 2 percent is obtained. In general, the maximum volume of water per bag of cement should not exceed 6 gallons when the concrete is to be exposed to weathering in the midwestern section of the United States.

Forty-three years ago when Duff A. Abrams stated his well known water-cement ratio law concerning concrete strengths, there was no realization of the important part water has in the making of quality concrete. In the years preceding 1918 there had been cycles of wet concrete and dry concrete. It was reasoned during a dry-to-wet trend that if a little additional water was good for the concrete, more would be better. Then it would be realized that the concrete was too wet and a trend to dry concrete would develop and continue until the concrete was too dry.

Commissioned in 1915 to make a study of the various factors having a bearing on the proportioning of concrete, Abrams reported after testing about 50,000 specimens that "with given materials and conditions of test, the quantity of mixing water used determines the strength of the concrete, so long as the mix is of a workable plasticity."

In the decade following the publication of Abrams' water-cement ratio strength law, there were many who questioned its validity. Abrams had used for his cement a mixture of four brands available in the Chicago area. The aggregates were sand and gravel from Elgin, Illinois. When other materials are used under different conditions, it is not unreasonable to expect that the strengths secured may be different from those secured by Abrams.

Abrams plotted his test results, strength against water-cement ratio. The points spread over a fairly wide belt but Abrams drew a smooth curve through the belt. Strength results secured by others were expected to fall exactly on the curve. We ask: Is this reasonable? Abrams did not put any numerical values in his statement of the law and we feel that any attempt to establish an exact relationship between strength and water-cement ratio for any and all combinations of materials and under all conditions of testing is unwarranted.

Following this early questioning of its validity, there has been general acceptance. During this period, however, five types of non-air-entraining and three types of air-entraining portland cement have come into general use. In addition use of admixtures in concrete for a variety of purposes has become accepted practice. It is obvious that all concretes made with 6 gallons of water per sack of cement will not have the same strengths regardless of the materials used.

Again the validity of the law is being questioned and some are going so far as to say that it should be written off as a bad experience. The implication to many persons, when the validity of the law is questioned, is that the amount of water used in making the concrete is of no consequence and any amount therefore may be used. To the

authors of this article the amount of mixing water is just as important today as it ever was and it has always been highly important.

Let us return again to the cement cylinders and examine the relationship between weight and water-cement ratio for cylinders of equal size as shown in Figure 3. Cylinders were made with 4, 5, 6, 7, 8 and 9 gallons of water per sack of cement. All are of the same size. The height of the black bar behind each cylinder indicates its weight.

Figure 3: Hardened neat cement cylinders of the same size made with different water-cement ratios. Height of the black bar behind each cylinder indicates its weight.

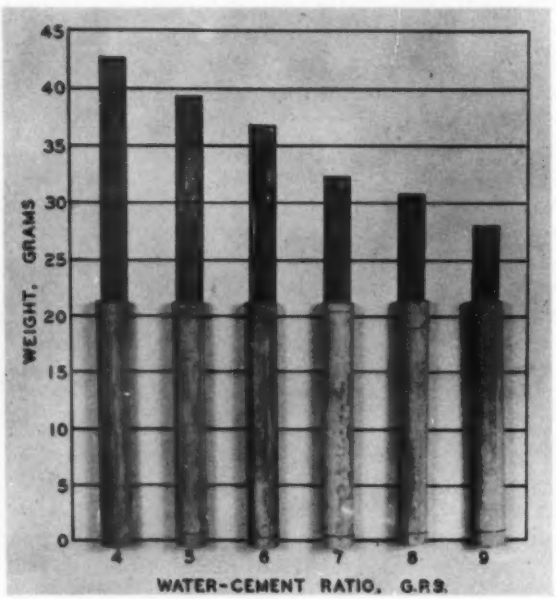
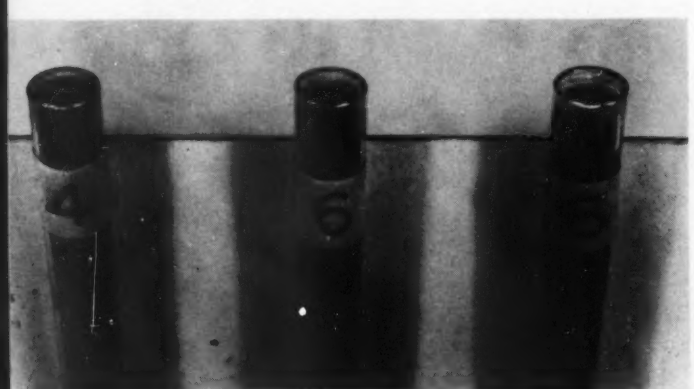


Figure 4: Hardened neat cement paste made with different water-cement ratios shown in glass cylinders. Note the increased amount of shrinkage with increased water-cement ratios.



For the cylinder at the left, with 4 gallons of water per sack, the weight after drying is 43 grams; for the cylinder with 6 g. p. s. the weight is 37 grams; while the cylinder at the right with 9 g. p. s. weighs only 28 grams. It is obvious that as the amount of water per bag of cement increases, the amount of cement in a given volume of the cement paste decreases. Since the source of the strength developed by the cement paste is in the cement, it is important to use as little water as possible, thus not diluting the paste.

Now that basic principles concerning mixing water have been explained, why is it important to place water on the concrete, or to prevent loss of water from the concrete, during the curing period? In order for concrete to develop strength, the cement paste must develop strength. In the development of this strength there is a chemical reaction between the cement and the mixing water, often called the hydration of the cement. This process of hydration may continue for a long time so it is important to retain a sufficient amount of water in the concrete for hydration purposes. Retention of water in the concrete may be accomplished by maintaining a supply of water on exposed surfaces, or by use of watertight barriers at the surface.

Loss of water from the cement paste immediately after the concrete is placed may cause small cracks to develop in the concrete. Portland cement is a fine powder, so fine the individual particles are not visible to the naked eye. About 90 per cent of the particles in an average portland cement will pass through a sieve having 40,000 openings per square inch.

For the moment let us assume that there is no reaction between the water and the cement. When water is evaporated slowly from the paste, the volume of the paste decreases. The surface tension of the water remaining in the paste draws the particles closer and closer together. If the paste is not mixed with aggregate to form concrete, shrinkage can take place without any cracks developing.

Since there is in reality a chemical reaction taking place between the water and cement, it is important that we prevent loss of the mixing water in the early stages to prevent any shrinkage from taking place. If no shrinkage takes place there are no cracks in the paste and all the spaces between the particles of aggregate are filled. Shrinkage cracks in the concrete are definite planes of weakness and may be the beginning of cracks extending entirely through the concrete.

An attempt has been made to demonstrate this item of shrinkage by placing cement paste containing 4, 6 and 8 gallons of water per sack of cement in separate glass tubes, as shown in Figure 4. The surface area for evaporation is small in relation to the volume of the paste. As a result

shrinkage is not as much as it should be. It is apparent, however, that the shrinkage decreases with a decrease in water-cement ratio.

The value of curing in reducing shrinkage is illustrated in Figure 5. Cement paste with a water-cement ratio of 6 g.p.s. has been placed in each of the glass tubes. The paste in the tube at the left was permitted to dry in laboratory air without any covering. The tube in the center was placed in the laboratory moist room for three days and then in laboratory air for 25 days. The tube at the right was placed in the laboratory moist room for 28 days. Close examination of Figure 5 shows that the air dried cement paste has the largest amount of shrinkage; that the paste cured for 3 days in the moist room has less shrinkage; and that cured 28 days in the moist room has the least shrinkage. In most cases 3 days of moist curing is sufficient to eliminate the possibility of shrinkage cracks developing on job concrete.

There is still the item of cost that must be considered in connection with the amount of mixing water used. For illustration purposes, let us assume that a strength of 4,000 pounds per square inch is desired and that a series of trial batches composed of the materials to be used on the job indicates that the water-cement ratio to use is 6 g. p. s.

What consistency shall be used? How is consistency measured? The method in widest use is the slump test, with which we are sure all our readers are familiar. From the standpoint of cost of concrete, it is much more economical to place low slump concrete than high slump. However, the concrete must be workable in order to develop full contact with the reinforcing steel and forms. Full contact with the reinforcing steel is necessary to develop the maximum bond strength; full contact with the forms is necessary to secure a smooth finish on the concrete. Workable concrete, however, does not need to be sloppy and runny; it can be of relatively low slump.

Let us now consider the cost of three consistencies using the 6 g. p. s. needed to produce the 4,000 psi. mentioned above. These three consistencies are shown in Figure 6. The concrete with the ½-inch slump contains 5.45 bags of cement per cubic yard of concrete and costs $14.57 per cubic yard for the materials.[1] The concrete with the 3-inch slump contains 5.80 bags of cement and costs $15.11 per cubic yard. The most expensive concrete, that with the 7-inch slump, contains 6.58 bags of cement and costs $16.32 per cubic yard. It must be kept in mind that all of these batches have a water-cement ratio of 6 g. p. s., and that increasing the amount of mixing water to increase the slump requires a proportionate increase in the amount of cement. To change the slump from ½ inch to 7 inches requires in this case an increase of 1.13 bags of cement per cubic yard of concrete, or slightly over 1/6 of a bag for each inch of increased slump. Mechanical vibrators are handy devices for compaction of the stiffer mixes and are highly recommended.

This in brief is why the water content of fresh plastic concrete should be kept at the minimum. After the concrete sets or obtains its final volume the added water permits the hydration process to continue and thus permits the concrete to develop its maximum strength and durability with the minimum of shrinkage. The lower the slump within the range of workability the more economical the concrete will be. If these basic principles are fully understood and practiced, strong, durable, economical quality concrete will be the resulting product. END

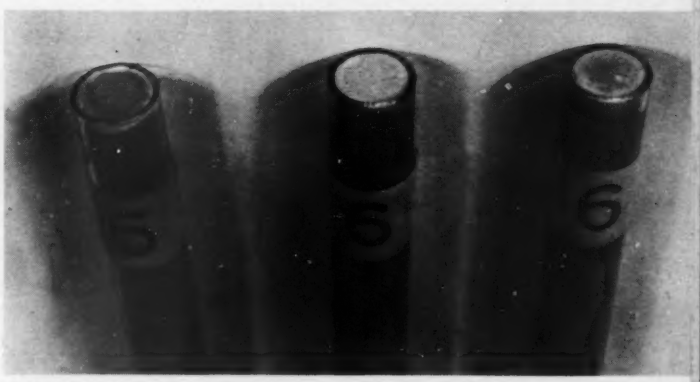


Figure 5: Hardened neat cement paste made with 6 gallons of water per sack of cement shown in glass cylinders. Paste in cylinder at the left was not cured, while the one on the right was cured 28 days in a moist room. The one in the middle was cured 3 days in a moist room.

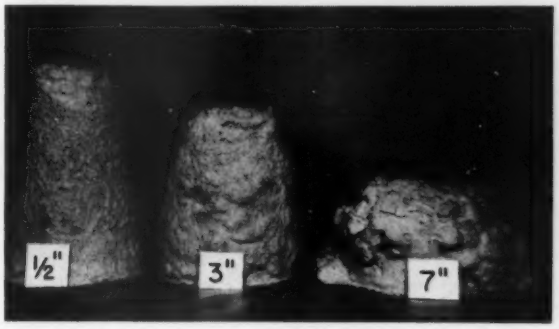


Figure 6: Showing concretes with slumps of ½, 3 and 7 inches.

[1]Cement is figured at $1.55 per sack, sand at $3.40 per cubic yard, and gravel at $3.80 per cubic yard.

KING SIZE

PRESTRESSING ANCHORAGES

One of the anchorage blocks for the highway bridge, Firth of Forth, Scotland, under construction. The 4½-inch diameter, steel tube ducts for the prestressing strands are shown before the final lift of concrete was placed.

The above-ground dead-end anchorages for the prestressing strands being levered into place. The end of each cable of four 1¼-inch diameter strands is enclosed within a zinc block surrounded by a steel cylinder.

FILE: Prestressing

WHEN THE RAIL BRIDGE over the River Forth in Scotland was opened in 1890 it was a landmark in civil engineering history. By present-day standards (with high-grade steels and precision design) the amount of material used for the bridge was enormous. Today a highway bridge is being built adjacent to the old one, to replace present ferry facilities. The new suspension bridge promises to be a monument to just how far the material-saving economies of prestressing can be carried. When complete the bridge will have a total length of 3,300 feet. It will be the longest in Europe and the third longest in the world.

The big problem with a suspension bridge of this size is one of providing the necessary anchorage. In the solid rock of the Firth of Forth it was found that prestressing could provide a simple and very economic solution provided that wire of the desired strength could be obtained. A British firm of wire manufacturers successfully developed a fully-galvanized high-tensile steel prestressing wire strand for the bridge to withstand a specified breaking load of 350 tons. During tests the strands actually broke at 381 tons.

The anchorages for the bridge were tunneled 240 feet into bedrock, with steel tubes 4½ inches in diameter inserted to act as ducts for the prestressing strands. In all 456 ducts were needed. Assemblies of four 1¼-inch diameter strands were threaded through each tube. Dead-end anchorage of the strands, above ground, is by means of massive zinc blocks enclosed within steel cylinders. The ends of the strands were enclosed within the zinc blocks at the plant before shipment. Below-ground, live-end anchorage (where the prestressing force is applied) is provided by standard-type wedges. The total weight of prestressing strand used reached 630 tons.

A similar method has been used to anchor the concrete foundations for the 505-foot high towers of the bridge. Each foundation was cast with holes for 48 single prestressing strands and the rock was drilled at each point to a depth of at least 35 feet. Strands 1¼ inches in diameter were then threaded down into the rock and pressure grouted. Each strand was tensioned at the surface, using wedge grips, and the duct within the foundation was grouted. A total load of 9,600 tons was applied to the base of each tower in this way. END

Here is the current thinking on the cause and prevention of some of the more frequently encountered types of cracking in concrete.

SOME NOTES ON CRACKING

IN SPITE OF INNOVATIONS AND IMPROVEMENTS along many lines, there are several problems in the concrete field which hang on with nagging persistence. One of these is cracking.

Cracking can be classified into two general types: one form appears before the concrete hardens; the other appears after the concrete hardens. In each case, and regardless of whether or not the structure is weakened, the cracks are unsightly and undesirable.

The most common flaw showing up in newly placed concrete is plastic cracking. As the name indicates, this type of cracking shows up before the concrete hardens. The cracks begin to form soon after a slab is placed and while the concrete is still plastic. Plastic cracking appears most frequently on horizontal surfaces, but the cracks take no particular shape, direction or pattern.

There is no mystery concerning the cause of true plastic cracking. The cracks show up when the surface of newly placed concrete dries too rapidly. Drying, in turn, comes about too swiftly when the evaporation of water from the surface of the fresh concrete gets out of hand. The rate of evaporation, as much as any other factor, determines whether the cracks will form.

As the concrete begins to set, water rises from within the mix to the surface. This process is known as bleeding. Bleeding keeps the surface damp even though evaporation takes away water constantly. The concrete cures properly if evaporation and bleeding are in step with one another. Under ideal conditions, bleeding replaces the moisture that evaporates.

Evaporation is not an easy phenomenon to cope with. Frequently it is observed that a slab sets properly on one day and that a similar surface cracks on another day, notwithstanding the fact that the same construction methods are employed and the same quality control measures enforced. The answer often proves to be a marked difference in the rates of evaporation on the two days.

Four major factors determine the rate of evaporation. They are (1) relative humidity, (2) wind velocity, (3) air temperature, and (4) the temperature of the concrete.

Observe the weather conditions the next time you place concrete for a sidewalk or a floor slab. Then compare your observations with a similar job later on. You will be amazed at the correlation between the extent of cracking and the kind of weather you observed. Cracking is most likely to occur on a hot, dry, windy day.

Suppose the relative humidity drops from 90 percent to 50 percent. With such a drop, the rate of evaporation increases at least five times. Moisture is literally jerked from the concrete into the surrounding dry air. With a drop of relative humidity from 90 percent to 10 percent, the evaporation rate increases nine times.

The air temperature and the concrete temperature also have a significant influence on the rate of evaporation. Evaporation doubles when the air temperature and the concrete temperature each advance from 50 to 70 degrees F. The rate quadruples with an increase in temperatures from 50 to 90 degrees F.

From the standpoint of comfort, a gentle breeze may come as a welcome relief on a hot summer day. But it can play havoc with newly placed concrete. For example, the evaporation rate increases four times with an increase in wind velocity from zero to 10 miles per hour.

At times plastic cracking occurs even when the air is cool and the humidity is high. Under such circumstances the concrete temperature may be the cause of the trouble, since evaporation is bound to accelerate when the temperature of the concrete is higher than the air temperature.

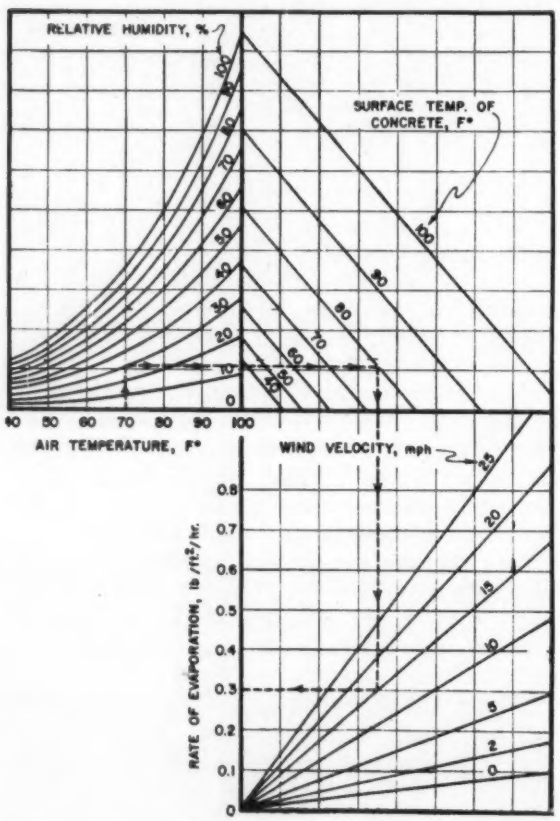
Since the weather pattern as reflected by air temperature and relative humidity cannot be influenced, protective measures should be taken as a matter of routine to offset the effects of hot, dry air. Evaporation can be controlled. In fact, its control is one secret of successful concrete work.

Many cracks can be avoided by adhering to one of the basic tenets of all good concreting: Start curing as soon as possible. Give the surface its final troweling, then proceed with whatever curing methods seem best for the circumstances. White membrane curing compounds are often excellent, but sand, wet burlap, polyethylene film, or light-colored paper will also usually do the job.

Timing is always important. Faulty construction methods may cause excessive and unnecessary delays in curing. Troweling sometimes can be speeded up without sacrificing a satisfactory finish. In some instances, a crew may place a considerable amount of concrete and then carelessly

Evaporation Rate Chart

The graph below, published originally by the National Ready Mixed Concrete Association, provides an easy means of estimating the evaporation rate on any specific concrete slab in order to determine when extra care must be exercised to prevent plastic cracking. The dashed lines and arrowheads illustrate the estimation of evaporation rate under the following conditions: air temperature 70 degrees F.; relative humidity 30 percent; concrete temperature 80 degrees F.; and wind velocity 15 miles per hour. For these conditions the chart shows an evaporation rate of 0.3 pounds of water per square foot of slab per hour. Since the possibility of plastic cracking often exists when the evaporation rate is as little as 0.1 pound per square foot per hour, it is obvious that some protective measures should be adopted whenever the estimated rate is substantially higher than that amount.



SURFACE EVAPORATION FROM CONCRETE

To estimate evaporation rate:

1. Enter top section of chart at appropriate air temperature and relative humidity.
2. Move right to line corresponding to the concrete temperature.
3. Move down to line approximating the wind velocity.
4. Read evaporation rate on scale, left of this point.

delay the curing. Such delays can easily be avoided.

Plastic shrinkage cracking may sometimes occur even before final troweling. When this happens, early curing is of course no longer the solution. To avoid such cracking, consider applying a fog spray during the period of early hardening before a final troweling; or alternatively, use a wet burlap cover, allow the surface to harden to some extent, and then proceed with the troweling. There probably will be no cracks.

It will always help things along to dampen the subgrades and forms. This additional moisture promotes bleeding. Aggregates should also be dampened, particularly if they are dry and adsorptive—a problem that need be of little concern to the contractor who uses ready mixed concrete.

It is the ready mix producer's business to cooperate in delivering a mix that is appropriate for the existing weather conditions. When the air is hot and dry, avoid a mix containing an excessively high cement content. Look with suspicion on a mix containing large amounts of fine aggregates.

If necessary, erect wind breaks to guard against the drying effects of brisk winds. On some jobs, wind breaks may be impractical from the standpoint of cost. But such devices often can be put up with materials that are at hand and with no particular strain on the budget.

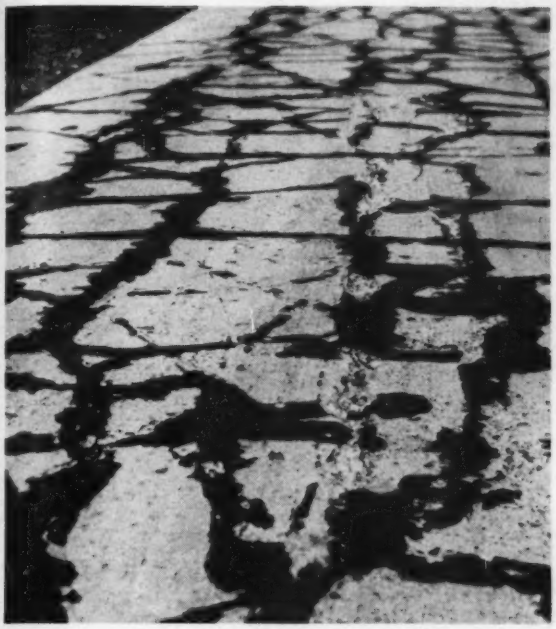
Protective shelters are traditionally looked upon as a wintertime necessity, but under extreme conditions they can be equally valuable in the summertime. Often a covering may be the only sure way to protect concrete from the hot sun, particularly when there is a delay between placing and finishing operations.

Another cause of plastic shrinkage cracking is known as syneresis. This is a chemical reaction in which the cement gel shrinks and water escapes rapidly. Usually cracks that occur as a result of syneresis can easily be erased by reworking the plastic concrete and closing the cracks. They seldom reappear.

Many practices that eliminate drying shrinkage also will discourage other causes of pre-hardening cracking. For example, proper attention to the mix often prevents settlement cracking. Settlement is no particular hazard when the mix contains well-graded aggregates and low water content. Adequate compaction is another safeguard.

Careless formwork often results in cracking. A poorly designed form sometimes moves under the impact of newly placed concrete. Cracks then appear. Closely tied in with this problem is the movement of subgrades. The subgrade must be firmly packed to avoid trouble.

Contraction cracks are among those occurring most frequently after the concrete hardens. Temperature variations are largely responsible for these cracks. Ice and snow contribute to the



This severe cracking in a highway pavement was attributed to an excessively low water/cement ratio. The mix contained only 2.4 sacks of cement per cubic yard.

Restrained by the heavy concrete step (top of picture) around which it was cast, this sidewalk developed an unsightly crack when contraction took place. The dummy joint should have radiated from the corner of the step.

trouble. Such cracks can be avoided by the proper spacing of contraction joints. Make sure that all exterior slabs are sectioned off in reasonable lengths.

Stress concentrations are another major cause of after-hardening cracks. Tensile cracks can almost always be anticipated in reinforced concrete. As a rule, these cracks are objectionable only from the standpoint of appearance. In some instances however they result in structural weakness. Efforts should always be made to control the width of such cracks.

The width of tensile cracks can be reduced by increasing the bond between the concrete and steel. Suppliers say that an improved type of reinforcing bar now makes a stronger bond and reduces the width of tensile cracks 20 to 40 percent.

The oxidation of reinforcement bars sometimes leads to trouble, particularly if insufficient cover is provided. As the bars rust, new stresses occur, and the concrete begins to crack. The use of high quality, impermeable concrete should help.

Chemistry also enters the picture once the concrete hardens. Cracks sometimes break out in bridges, dams, and other mass concrete structures as a result of a reaction between aggregates and cement. The reaction causes an expansive gel to form, resulting in large cracks. The best way to avoid such cracking is to make sure that reactive aggregates are eliminated from the mix. Such cracks usually appear from six months to a year after the concrete is placed.

Builders of such massive works as bridges and dams have still another problem. In every job, they must do something to cope with the heat of hydration. This heat creates temperature differences within the interior of the concrete. At the same time variances in the surface temperature add further complications.

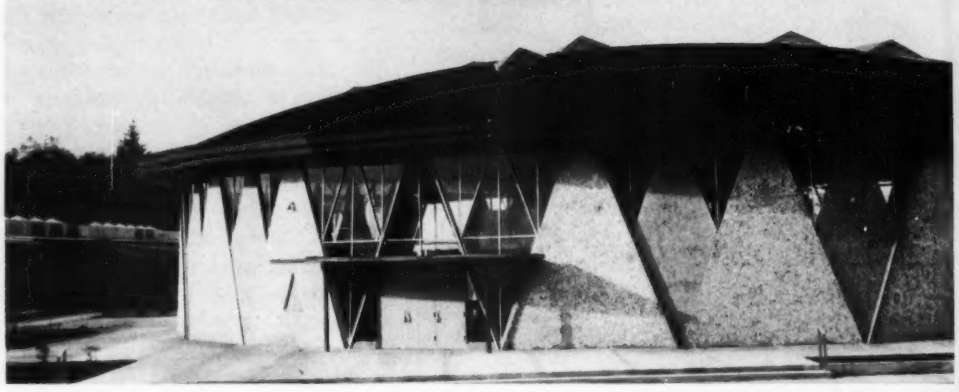
Temperature changes within the interior and at the surface create extreme tensile stresses. Unless they are controlled, these stresses bring about unusually dangerous cracking. Such cracks are not only unsightly but are also an invitation to weathering and disintegration.

Some engineers suggest the use of double-walled steel forms for controlling cracks in bridges and dams. Refrigerated water is circulated within the forms, providing a cooling system for the great mass of concrete. Another type of cooling system consists of water pipes embedded in the concrete.

The average concrete contractor may not be concerned with the problems of the bridge men and the dam builders, and he can almost always get along without a refrigeration system at the construction site, especially if he uses ready mixed concrete. But if he takes pride in his work, he will surely give thought to the problem of cracking. Cracks can be eliminated. END

LEFT: View of classroom building, landscaped pool and circular gymnasium at Mountlake Terrace Senior High School, Seattle, Washington.

BELOW: Close-up view of geodesic dome gymnasium. Exteriors of buildings are of tilt-up concrete panels surfaced with crushed white marble.



SCHOOL IN THE ROUND

GEODESIC DESIGN and the use of concrete effected notable savings in the construction of Seattle's new $1,768,083 Mountlake Terrace Senior High School. The architect credits an estimated $40,000 savings in over-all costs to the unusual circular shape, and to the choice of concrete as the building material. He explains that a circular design gives the smallest number of lineal feet of wall to enclose a given space.

The $13.85 spent per square foot is well below the Washington state matching limit of $13.96 a square foot. The school, with 128,922 square feet of usable space, was built at a per pupil cost of $1,786.08, also below state limits. Total cost included a 6 percent architect's fee, a 4 percent state sales tax and all additional items such as landscaping.

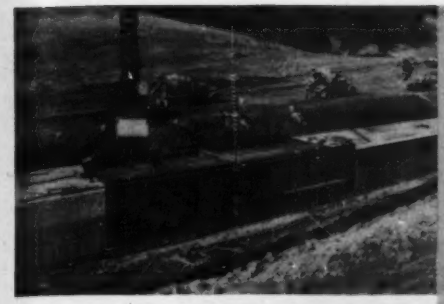
Facilities cover 40 acres of buildings. The classroom buildings have 50 teaching stations. Administration, cafeteria, library and student room are in another wing separated from classroom by a courtyard. Shops, music building, gymnasium and storage areas are in another wing.

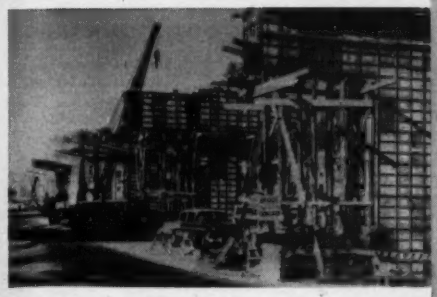
The gymnasium encloses 12,500 square feet of usable space. Had it been necessary to span this space in a rectangular design with the same number of square feet, it would have required a truss of at least 12 inches in thickness. This greater thickness would have increased the wall height to a point where the additional square feet of wall space would have boosted the costs sky-high.

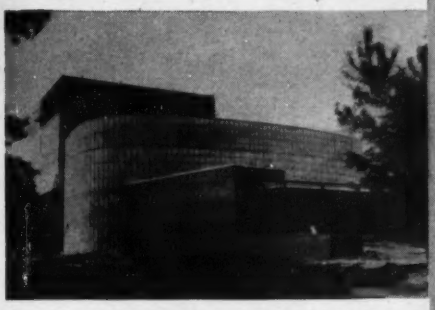
Construction involved the application of exterior walls consisting of 6-inch thick tilt-up panels of concrete faced with crushed white marble to provide an attractive, damageproof, no-maintenance exterior. The panels were cast at the site in wooden forms on pretreated floor slabs. Steel reinforcement was added, the white crushed marble applied, and the panels were then raised into place by huge cranes.

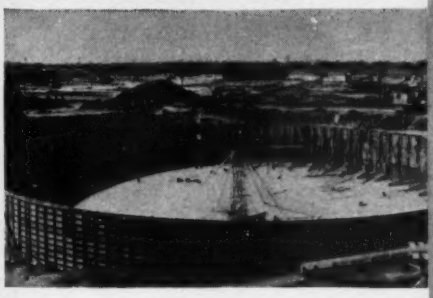
The exterior walls of the gymnasium consist of triangular concrete panels faced with the same gleaming chipped white marble. Space between the panels has been glassed in and in the interior alternate panels are painted chartreuse and blue-gray. END

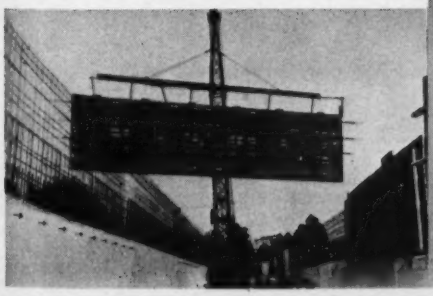
FILE: Architectural











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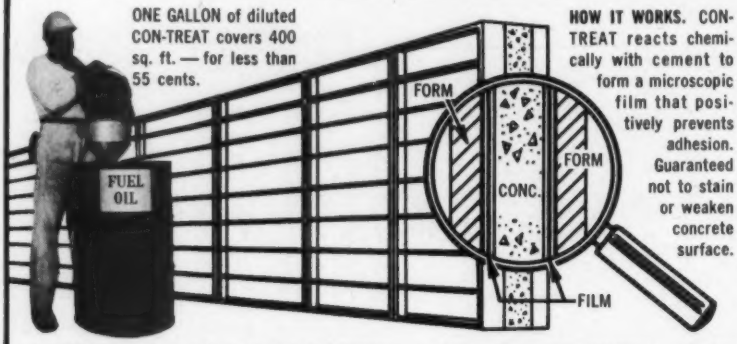
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problem clinic

surface carbonation

Question: What is the best way to protect concrete floors against surface carbonation when heaters must be used in cold weather?

Answer: Concrete Construction reported on this problem in some detail in the October 1956 issue, page 2. These three specific recommendations were made: (1) Use temporary heaters which do not allow combustion gases to contaminate the air. (2) If unvented heaters must be used, protect the concrete with membrane curing, making sure that the surface is completely sealed. Burlap, for example, may not provide sufficient protection against carbonation. (3) Exhaust combustion gases outside of enclosures whenever salamanders or unvented heaters are used.

wear resistance

Question: What are the factors which affect the resistance of a concrete floor to wear?

Answer: Wear resistance is linearly proportional to compressive strength within the range of 3,000 to 6,000 psi; at strengths below 2,500 psi wear resistance reduces very rapidly. Aggregates for a wear resistant floor should be tough, hard and dense. Wear resistance increases with time of curing up to a maximum of about 30 days, and with drying up to as long as 40 days. Certain materials, such as magnesium fluosilicate, zinc fluosilicate, sodium silicate, aluminum sulfate and zinc sulfate, as well as a number of proprietary compounds, are also used as floor hardeners.

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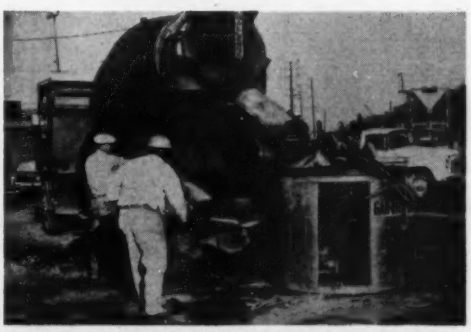
larger gates... lower loading heights



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sidewalk pitch

Question: How much pitch for drainage purposes should be built into a standard sidewalk, and what is the best way of providing for it?

Answer: From ⅜ to ½ inch is generally considered adequate. This amount of pitch can best be provided by simply setting the form higher on one side than on the other.

settlement cracks

Question: What measures can be taken to prevent the formation of settlement cracks at the top corners of beams, doors and windows above columns?

Answer: Probably the best precaution is to interrupt the placing of concrete at the tops of the columns for about two hours to permit settlement to take place before casting beams.

Darex Diary

by Mel Prior
Member, American Concrete Institute
Technical Service Manager, Construction Chemicals

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(No. 22 of a series)

A Look at Structural Lightweight Concrete

AGGREGATE USED for structural lightweight concrete has been available for over 40 years. Until recently, however, it has not been used extensively by the concrete industry and there is still much to be learned before its maximum potential can be realized.

The nature of this type of aggregate is such that it is virtually unheard of to use it without chemical admixtures. It is inherently angular and porous, requiring a relatively large quantity of paste and/or water for efficient handling and placing.

From the time lightweight aggregates were first introduced for structural purposes, investigations indicated that air entrainment was an absolute necessity for lubricating the mix and maintaining a minimum water/cement ratio. Air entrainment permits the aggregate to move more readily within the mix by minimizing particle interference. However, this is only one phase of the problem since the mix plasticity is also affected by the paste.

More recent research has led to the recommended use of water-reducing admixtures, as well, in lightweight concrete. Such admixtures provide the advantage of plasticizing the paste with a minimum quantity of water. The relatively high bleeding tendency of this type of concrete is thus further reduced.

Since air content is an important factor in lightweight concrete it is necessary to make frequent air determinations. The volumetric method, ASTM Designation C 173-58, sometimes referred to as the Roll-A-Meter method, has proved to be the most satisfactory procedure. The added air is measured without interference from the air which may already be trapped in the pores of the nonsaturated porous aggregate. The need of a correction factor which a pressure type meter would entail is thus eliminated.

Roll-A-Meter for measuring entrained air in lightweight aggregate concrete. Distributed by Charles R. Watts & Co., Seattle, Wash.

On performance, DAREX AEA Air Entraining Agent and WRDA Water-reducing Agent have come to be regarded as essential ingredients in top grade lightweight aggregate concrete.

The combination of these admixtures reduces the water requirement, thereby reducing bleeding and volume change due to drying shrinkage. At the same time, strength is increased with no increase in density. Finishing operations can be started with a minimum delay and yield will be more realistic.

silicone treatment

Question: Does treatment with silicones have any major effect on the resistance of concrete to weather and ice-melting chemicals?

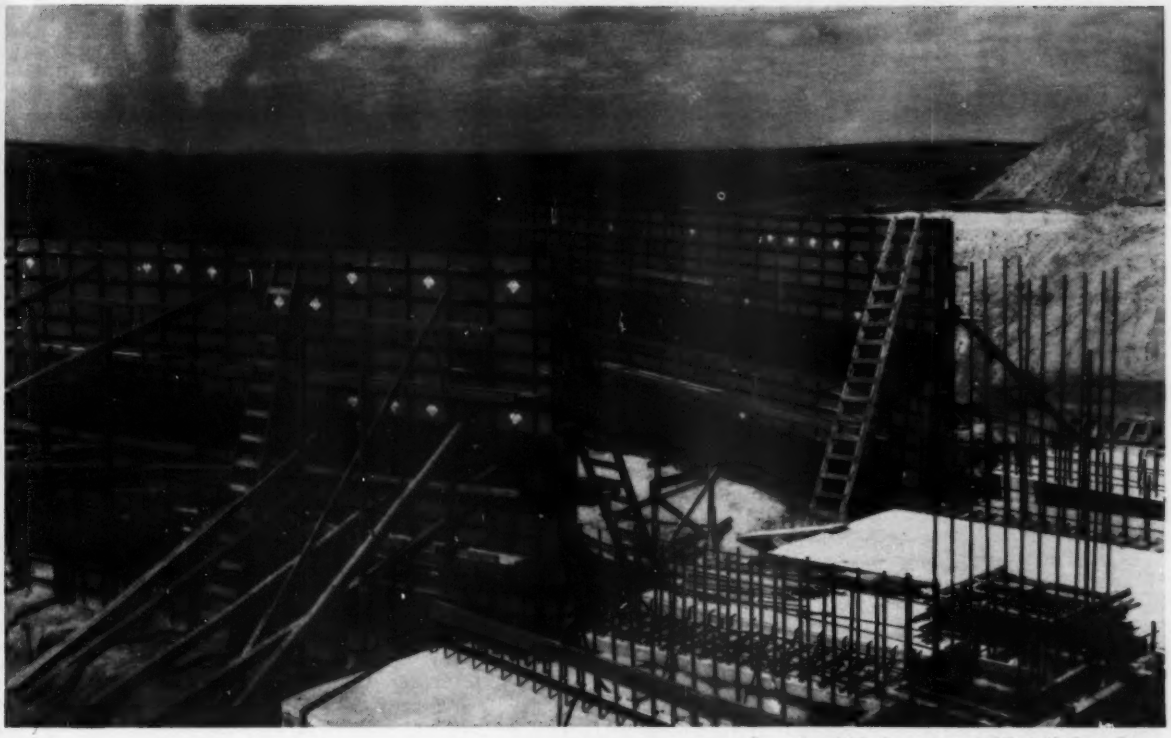
Answer: There is mounting evidence to indicate that silicones are beneficial. Most of the curbing on a New York state highway bridge was treated with water soluble sodium methyl siliconate at an optimum concentration of 2 percent silicone solids. Two years later this non-air-entrained concrete showed no signs of spalling in the treated sections, while the untreated control section was heavily spalled.

Silicone treatment also has a valuable safety feature, since it keeps the light reflectance of wet concrete very close to that of dry concrete, as compared with the 35 to 50 percent reduction which takes place when untreated concrete becomes wet. The accompanying photograph, taken during a rainstorm, shows how the silicone-treated portion of a bridge deck rejected moisture while the untreated portion at the left of the picture became dark and watersoaked.

progressive popping

Question: What is the most likely cause of progressive popping of a concrete slab while spalled material is being removed in preparation for resurfacing?

Answer: This condition usually occurs because of the redistribution of stresses in the slab as damaged material is being removed. The recommended practice is to shore up the slab before repair work is started and to keep the shoring in place until the new surface has been completely cured.



Operational Missile centers at Offutt Air Force Base.
J. Hilding Johnson, Inc., Gary, Indiana, contractor.

Symons Steel-Ply Forms Solve Missile Base Problems

Winter weather didn't stop J. Hilding Johnson, Inc., Gary, Indiana, contractor for the three operational Missile centers at Mead and Arlington, Nebraska, and at Missouri Valley, Iowa. Subbing 36,000 cubic yards of concrete work from prime contractor Malan-Groves, Johnson was prepared for winter, and shoved ahead its construction schedule to a 24-hour around-the-clock basis.

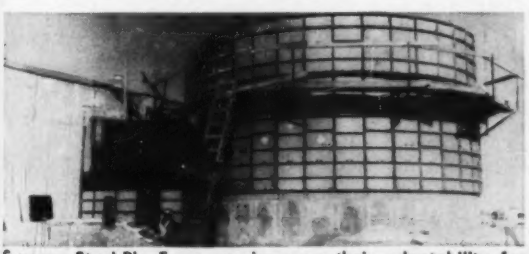
Symons Steel-Ply Forms were used to facilitate speedy construction and solve other contract problems.

Cut Over-All Costs

Direct number of carpenter hours in the field were reduced and administrative-wise, there were about 25 percent fewer men on which to issue checks, keep time records, and other necessary details.

Flexibility was Big Advantage

If weather interfered with a pour scheduled down in a hole, forming and concrete work still could proceed at some other location above ground.



Symons Steel-Ply Forms again prove their adaptability for circular forming.

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The corps of engineers required triple-row bracing or external waling on both sides. However, the corps gave permission to try one 25-foot-high wall, braced only on one side. Based on results, permission was given to use the system on the remaining work. Many man hours were saved. And the method cut weeks off the over-all construction schedule.

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Eliminating yard congestion at the job site was important, particularly during rainstorms and during the freeze-thaw cycles of early winter.

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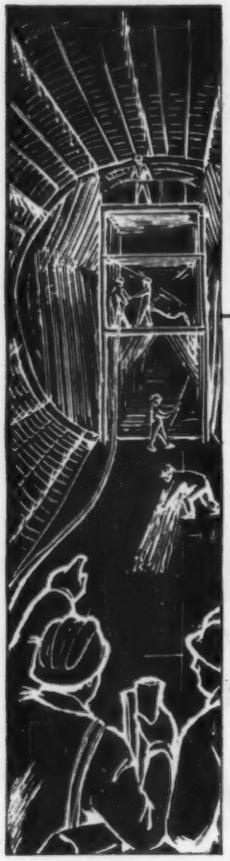

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elephant trunks

Question: Are there standard manufactured "elephant trunks" for placing concrete in narrow walls without segregation?

Answer: Gar-Bro Manufacturing Company, 2415 East Washington Boulevard, Los Angeles 21, makes rubber trunks up to 30 feet in length and in 8-, 12-, 16- and 20-inch diameters.

cores with steel

Question: What effect would the presence of reinforcing steel have on the compressive strength of a concrete core?

Answer: Steel in a horizontal or nearly horizontal position would probably tend to result in a lower compressive strength test. Cores containing steel should be rejected whenever possible.

steepness of belts

Question: How steeply may a conveyor belt for concrete be inclined without seriously reducing its capacity?

Answer: The slump of the concrete is an important factor. With a slump of 2 inches or less the incline may be as much as 24 degrees; for 6-inch slump concrete the downhill flow of the material would probably be excessive for angles over 12 degrees with the horizontal.

pyrite in aggregate

Question: Is the presence of pyrite in an aggregate likely to be injurious to concrete?

Answer: The presence of an appreciable amount of pyrite (iron disulphide) is undesirable, since this compound readily decomposes into weak products such as iron sulphate and limonite, along with the formation of sulfuric acid.

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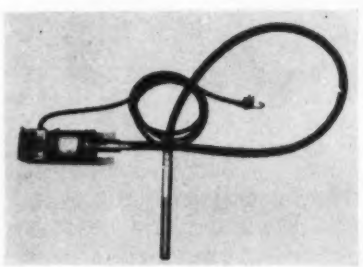
miniature truck crane

An authentic scale miniature of the world's largest truck crane is now offered by the manufacturer. With an apparent eye on the next generation of heavy equipment men, the firm also offers a scale miniature of a power shovel. The reproductions, made by the Lionel Corp. of New York, include such details as sliding outrigger beams and jack-floats for the truck crane. In addition, the truck crane replica has a revolving operator-engine cab, tandem axles with dual wheels, and a realistic folding boom. The shovel has revolving tracks and upper cab unit, plus a movable boom and dipper sticks. Available from the Advertising Dept., Construction & Mining Div., Harnischfeger Corp., 4445 W. National Ave., Milwaukee, Wis.



portable concrete vibrator

This new compact electric concrete vibrator is specifically designed for use on small pours. This portable vibrator, with a standard shaft length of six feet, is powered by a ½ horse-power motor delivering up to 10,000 vpm. It is recommended by the manufacturer for use in hard-to-reach areas and small jobs where large equipment might be impractical. Marvel Equipment Corp., 215 Eagle Street, Brooklyn 22, New York.

Gates

WEDGE-LOCK

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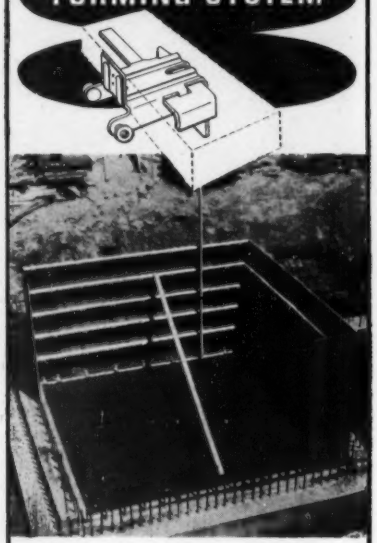

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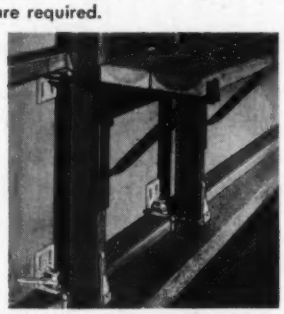

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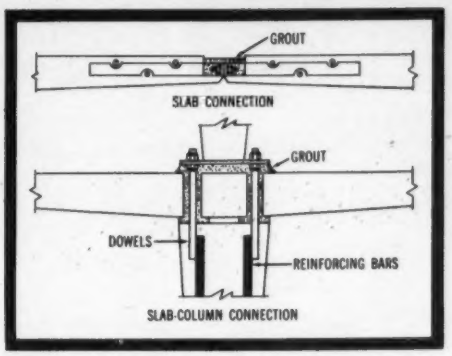

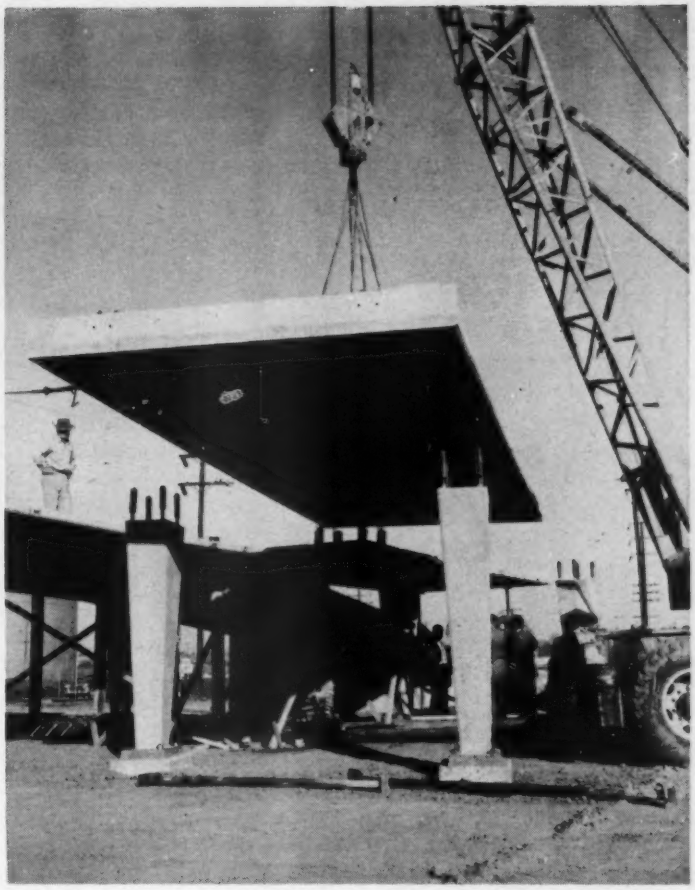

PHOTOS THROUGH COURTESY OF TISHMAN RESEARCH CORPORATION, NEW YORK, N. Y., DESIGNERS AND DEVELOPERS OF TIERPARK GARAGES

5000 psi in sixteen hours with SIKA SET

Grout and dry pack mortar with rapid strength development and minimal shrinkage is essential for the fast erection of the new Tierpark Parking Structures developed by Tishman Research Corporation. Composed of only three elements — slabs, columns and ramps — a Tierpark structure is erected within a matter of days.

Mix proportions for high strength grout and dry pack mortar were developed at the Sika Concrete Laboratory. Sika Set liquid, diluted 1:3, added to the dry pack produced compressive strengths exceeding 5000 psi at sixteen hours. Sika Set, diluted 1:4, added to the poured grout produced compressive strengths exceeding 3000 psi at sixteen hours. Proportions of 1 part Type III cement to 1-1/2 parts sand were used.

Structural concrete was initially retarded by the use of Plastiment Retarding Densifier to facilitate finishing — with rapid strength gain as an added bonus to the manufacturer of the precast, prestressed elements.

For full details on Sika Set Shrinkage Reducing Accelerator and Plastiment Retarding Densifier ask for your copies of SET-661 and PCD-59. Offices and dealers in principal cities, sixteen affiliate manufacturing companies around the world. In Canada, Sika Chemical of Canada, Ltd.; in Latin America, Sika Panama, S. A.

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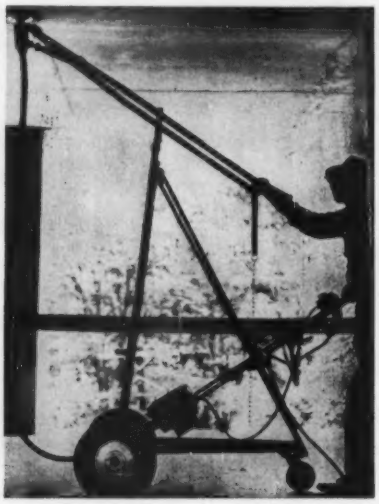
SIKA CHEMICAL CORPORATION

Passaic, N. J.

HOW TO GRIND CONCRETE CEILINGS



More and more building specifications require finely finished concrete ceilings. Because of this new requirement, Stow Manufacturing Co. has developed the Stow CG Ceiling Grinder—a special machine designed to grind off form marks and fins, cut off nails and smooth the entire surface.

With this machine, one man can average 4,000 square feet per day. Simple to operate, it pushes along like a baby carriage.

All models have a 1 HP totally enclosed motor operating at 3450 RPM. The disc is a 9" Bayflex of cotton fibrous material with a silicon carbide abrasive bonded with resin.

Two models are available:

CG 10—for ceilings 8 to 10 ft. high
CG 18—for ceilings 10 to 18 ft. high

Also Available With Gas Engine

Stow Manufacturing Co. also makes a complete line of portable electric flexible shaft grinders for both wet rubbing and dry grinding walls. For more information on the Stow CG Ceiling Grinder and a copy of Stow's "Grinding Concrete" pamphlet, which gives the proper speeds for both wet rubbing and dry grinding, contact your Stow distributor or send in the coupon below. Stow also makes a complete line of concrete vibrators, rotary trowels and screeds.

STOW MANUFACTURING CO. Dept. H-2
354 Shear St., Binghamton, N. Y.

Please send me your pamphlet, "Grinding Concrete."

Name..... Title.....

Company.....

Street.....

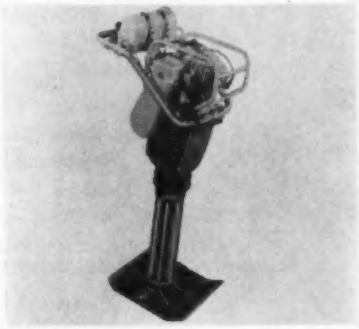
City..... State.....

coating for surfaces

Designed for spray application to cover defects on masonry surfaces, this coating primes, fills and textures. It can be used on exteriors or on interiors below grade, can be mixed integrally with masonry paint or painted after application. Western Mineral Products, 4725 Olson Memorial Hwy., Minneapolis 22, Minn.

paving compound

A bituminous patching and paving compound is said to adhere readily to concrete and other paving surfaces even when applied outside in rain or freezing weather. No special surface preparation or primer is required. The surface is merely flushed with water to remove dust and debris, and the material spread and tamped or rolled. It sets by compression, and is ready for the heaviest traffic immediately, according to the manufacturer. Paramount Industrial Products Co., 2717 E. 75th St., Cleveland, Ohio.



compactor

Effective for compacting many types of soil, this compactor permits compacting against abutments, in trenches and in other working areas of limited space. Weighing 120 pounds, it features a lifting eye, carrying handle, rewind starter, and centrifugal clutch for easier starting. Master Vibrator Co., 1752 Stanley Ave., Dayton, Ohio.

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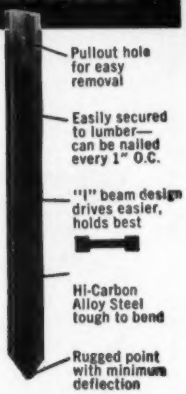
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Hi-Carbon Alloy Steel tough to bend
Rugged point with minimum deflection

Can Be Reused Indefinitely

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Swift and Company Packing Plant, Wilson, North Carolina. ARCHITECT: Swift and Co. Staff. CONTRACTOR: F. N. Thompson, Inc.

... eliminates the possibility of moisture migration into the new Swift Packing Plant

In an attempt to eliminate moisture migration into the structure the construction industry has tried many products. Some proved partially effective . . . many failed . . . *one* has emerged as the "quality" product or *true* vapor seal—"Premoulded Membrane." Daily more and more architects, engineers and contractors are specifying and using "PM" wherever good design practices call for the modern, efficient method of eliminating moisture migration into the structure. "PM" is waterproof; offers a water-vapor transmission rating of only .0066 grains per hour per square foot. "PM" is strong; provides a monolithic seal without open seams or voids; will provide complete moisture protection for the life of the structure. Dampness, condensation, paint and insulation failures, etc., *can be eliminated* only if the structure is isolated from the site by a *true* vapor seal . . . "Premoulded Membrane."

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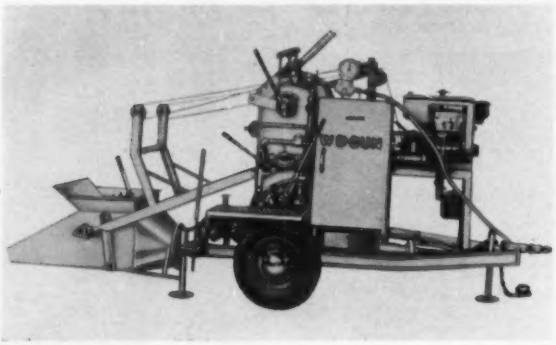
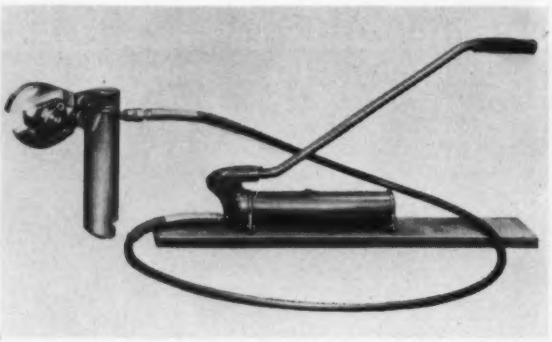


concrete gun

This fully portable gun is capable of both wet or dry gunning and pressure grouting for the all-around contractor who handles many different kinds of jobs. The gun features a skip loader which screens sand and cement into separate compartments, a built-in water meter variable feed control, a feeder providing continuous feed from a single outlet. It is operated with a simple foot control. Air Placement Equipment Co., 1012A West 25th St., Kansas City 8, Mo.



hand-hydraulic cutter

Powered by remote-control, hand-hydraulic pumps that force hydraulic fluid through high pressure hose to the ram assembly, this metal cutter cuts soft metals through ¾-inch diameter. It also handles medium-hard metals such as concrete reinforcing rods, brass, copper, aluminum, steel, iron and plastics through ⅝-inch diameter. Independent of outside power sources, it may be taken to the job wherever it is. H. K. Porter, Inc., Somerville 43, Mass.

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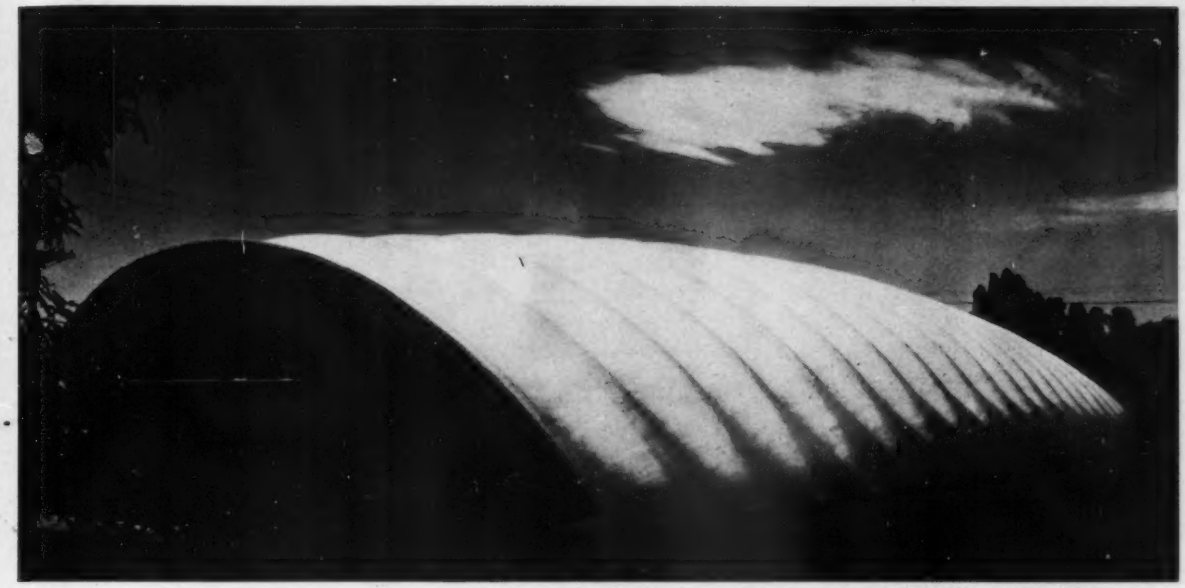

36 HALF-ARCH CONCRETE SECTIONS, site-cast then crane erected and tied by welded plates, form clear span, armadillo-shaped ice rink in Tarzana, Calif.

Thin shell concrete toroid houses skating rink

A CORRUGATED TOROID of reinforced concrete, the first such structure in America, proved to be an economical as well as unique enclosure for a California ice rink. The 4″ thick shell has a 100′ x 180′ base and is made up of 36 sections, cast on site. Arch of the toroid tapers from 32′ at center to 24′ at ends.

Each 10′ wide half-arch is corrugated and curved in two directions. Its base rests on a 20″ dia. x 23′ deep concrete pile, poured in place. Welding plates, cast into the centerline end, were welded to their companion sections.

Double curvature of the panels ruled out conventional forming. Casting pit was formed with an arched mound of earth left in the center. This mound was shaped into four beds, surfaced with concrete and plastered smooth. Nine progressively shorter panels were cast atop each other in each bed.

The problem of over-slumping in the concrete was solved after several trial mixes. The answer was a mix of ⅜″ top size aggregate with additive for workability. Compressive strength was 3,000 lbs. at 7 days.

Shell and foundation cost only $49,000. Total construction costs were $108,000, little more than $6 per sq. ft. Concrete was delivered to exact specification by truck mixers of certified design, capacity, mixing speed and water control accuracy.

PANELS WERE CAST in pancake stacks in four sculpted earth beds. Inserts for strongbacks were placed with reinforcing steel.

CRANES POSITIONED both panels of each arch and butted them for welding. After all panels were erected, dowels spanning 16″ wide pour strips between panels were spliced and welded. The pour strips were gunited to follow the contours of the shell. Contractor: Rains-McLellan Corp. Architect: Carl Maston, AIA. Structural engineer: Richard R. Bradshaw.

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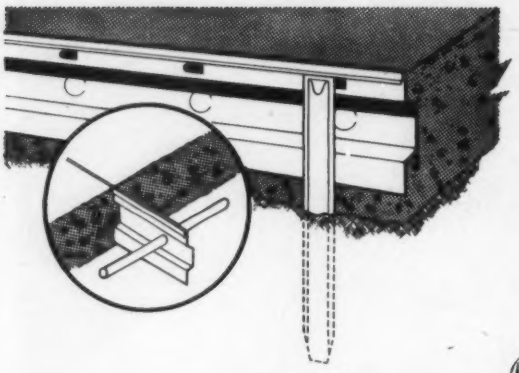

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